

LUNAR LINEAR RILLES, MODELS OF DIKE EMPLACEMENT AND ASSOCIATED MAGNETIZATION

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Introduction and Background: Lunar linear and arcuate rilles form from tectonic deformation associated with near-surface stress fields [1, 2] which have been attributed a variety of origins, including lithospheric flexure in response to mare basalt loads [3], and to the emplacement of dikes to near-surface environments [4]. We have been assessing the nature of dike intrusion as a source of near-surface stress fields sufficient to produce linear rilles [4, 5] and conversely, developing criteria to distinguish rilles plausibly caused by near surface dike intrusion from those formed by other mechanisms [6]. We have developed model predictions [5], photogeologic criteria [6], and have most recently been investigating the possibility of using measurements of magnetic fields by the electron reflection method to aid in the identification of candidate linear rilles formed by dike intrusions [4]. In this abstract we report on progress in the further assessment of data from these sources and on the identification of areas in which magnetization features appear to be associated with linear rilles.

Theory, Predictions, and Observations: A dike propagating from depth toward the surface generates a stress field in the surrounding rocks. As an upward-propagating dike nears the free surface, the accompanying stress field is progressively modified; stresses and associated strains at the surface become concentrated in two regions parallel with the strike of the dike plane and located on either side of the line of the potential outcrop of the dike on the surface. The separation on the surface between the zones of maximum elastic stress is essentially independent of the mean dike thickness and depends only on the dike tip depth [7]. However, the magnitude of the maximum stress is directly proportional to the dike thickness, as well as being dependent on the depth of the dike tip. As a dike tip rises towards the surface the stresses become sufficiently large that failure of the country rocks takes place in shear or tension at points well outside the process zone on both sides of the dike. Whether these initial failures are actually on the surface or at some finite depth below it is a function of relationships between the excess pressure within the dike, the dike width and the mechanical properties of the country rocks [8]. The failure planes soon intersect the surface, however, and a linear graben structure begins to develop. If the dike stalls at a sufficiently great depth there will be some undetectable small amount of surface extension and uplift. Shallower penetration will lead to a volume of melt being exposed to the relatively low pressure environment near the surface and will encourage the generation of a greater mass of CO since the chemical reaction producing it is pressure-dependent [9]. Sufficiently close approach of the dike tip

to the surface will cause new fractures to form and allow significant movements along parallel faults to occur. As the dike tip further approaches the surface, the main effect will be for the graben to become progressively deeper as more strain is accommodated. Very shallow intrusion may lead to further fractures developing on the floor of the graben and will encourage the formation of small secondary intrusions and possible eruptions.

These theoretical predictions support the idea that linear rilles may be the sites of subsurface dike emplacement. Specifically, from a morphological point of view, many dikes may intrude to sufficiently shallow depths that they will create graben, but there will be no surface evidence of eruptions. These are clearly the most difficult to distinguish from graben formed from stress fields not related to dikes. Several examples are known in which other evidence suggests that dikes exist below the observed graben. Rima Sirsalis, a 380 km long graben in the highlands, is characterized by a linear magnetic anomaly interpreted to be due to an underlying magnetized dike [10, 11, 4]. Thus, magnetometer and electron reflection experiments may provide additional information on the location of buried dikes and the origin of specific graben. A reasonable interpretation of this relationship is that the impact event excavated mare material from the top of a dike underlying the graben. In some cases, dikes may propagate sufficiently near to the surface to create a graben, but still not cause significant eruption of lavas [12]; in these situations, degassing of the upper part of the dike may cause the formation of gas/magma mixtures which might buoyantly rise to the surface or be forced to the surface through overpressurization of the upper part of the dike. In this particular configuration, the distribution of stresses anticipated in the vicinity of the dike tip can cause migration of magma and exsolved gas from the upper part of the dike to locations outward of the main graben bounding faults, a phenomenon likely to explain the distribution of cones at Rima Parry V [4]. Dikes reaching closer to the surface, but still not having associated extensive lava flows, should produce narrower graben, and any pyroclastic cones should be more closely associated with the graben.

Observations and Analysis: On the basis of the likelihood that numerous linear rilles could represent the surface manifestation of dikes emplaced to the vicinity of the lunar surface, and the fact that in at least one place on the Moon where there is a good correlation between a linear magnetization anomaly and a linear rille [10, 11], we have been reanalyzing data from Apollo magnetometer and electron reflection experiments to assess whether they can provide additional information on the location of buried dikes and the origin of specific graben. The method of

measuring lunar magnetic fields by the electron reflection method has been described elsewhere [10, 13, 14].

Rima Sirsalis is the site of a strong local magnetic field [10, 11] (Figure 1). It is a NE trending linear rille about 380 km in length located in the highlands south of Grimaldi (Figure 1); it averages less than 4 km wide and is 150-250 m deep. The depth to the dike top is estimated to be ~1700 m and dike width is estimated to be in the range 600-700 m [4]. These values compare with predicted dike widths of 600-800 m for dikes propagating from parent magma bodies at depths up to 300 km [15]. The magnetic data for Rima Sirsalis can also be used to estimate the average width of the subsurface dike given suitable assumptions about its magnetic properties. Srnka *et al.* [11] used various configurations of single and multiple dikes extending to various vertical depths from the surface and having various degrees of magnetization. Using a single dike model exemplified by their Figure 7 and varying the mean dike width and a range of remanent magnetization values it was found [4] that a mean dike width of ~430 m is consistent with the measurements if the magnetization. Thus, on the basis of these considerations, we conclude that a dike emplacement model for the Sirsalis graben and magnetic anomaly is plausible.

An additional anomaly is observed over the Fra Mauro/Bonpland region (Figure 1) where the reflection coefficient is distinctly above background but less than a factor of two of that seen at Rima Sirsalis. A large concentration of linear rilles is seen in this area. Rima Parry V, about 50 km in length, is a linear rille that is part of a series of graben-like features that cut the floors and rims of the craters Fra Mauro, Parry, and Bonpland. It begins in the south on the floor of Bonpland in the vicinity of Rima Parry VI, and extends NNE across the northern rim of Bonpland, descending to the floor of Fra Mauro, and continuing across the floor until it merges tangentially with the NNW trending Rima Parry I. Midway between the ends of the rille, the rille walls are obscured by deposits associated with a set of volcanic cones parallel to the western rille margin. Rilles in the vicinity of Rima Parry V cut the early Imbrian Fra Mauro Formation and are embayed by later Imbrian-aged maria [16]. On the basis of observations and empirical relationships, the average dike width is estimated to be about 150 m [4]. The estimated depth to the dike top is ~750 m. Thus, on the basis of these considerations and the presence of associated pyroclastic deposits, we conclude that the characteristics of Rima Parry V, and by association the adjacent rilles, are consistent

with formation by dikes which propagated from depth to near the lunar surface. The lower reflection coefficient values than at Sirsalis may be related to the smaller dike widths.

Preliminary Conclusions: On the basis of this analysis, we find that one of the prime candidates for linear rilles associated with dike emplacement on the basis of morphology and geology (e.g. Rima Parry V and associated rilles) is also characterized by a magnetic field anomaly plausibly attributed to magnetization of the dike. We are presently examining the area in more detail to correlate individual peaks with local features, and extending the analysis to other areas of the lunar surface covered by the Apollo 15 and 16 data.

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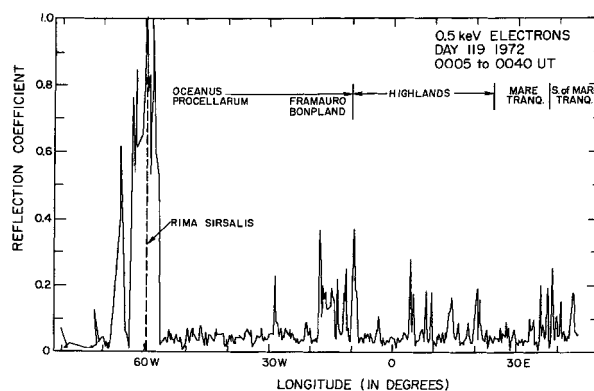


Figure 1.